Shaking Table Test of a Near Full Scale Low Damage Structural Steel Building: Structural Aspects

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Introduction

Recent severe earthquakes worldwide have put emphasis on building resilience. To achieve this, procedures for low damage seismic design have been developed to satisfy both the life safety requirement and the need to minimize the undesirable economic effects of required building repair or replacement following a severe earthquake. The performance of these buildings is dependent on whole building system interactions, which are difficult to determine by numerical modelling. The purpose of this project is to experimentally test the seismic performance of a complete, low damage, full scale building system incorporating a number of friction energy dissipaters in forms of sliding hinge joint asymmetric friction connection (SHJAFC), resilient slip friction joint (RSFJ), symmetric friction connection (SFC) and GripNGrab (GnG). This will also incorporate testing without and with non-structural elements (NSEs) to quantify their effect on the building response. Testing will be based on appropriately scaled actual earthquake records using two linked 70-ton shake tables at Tongji University, Shanghai, China. Unidirectional each axis and biaxial horizontal testing will be undertaken. The structure is expected to have at worst minor damage under a series of severe earthquakes. The design also aims to have economical methods for repairing and straightening such building systems after severe seismic activities, if there is a need. This paper focuses on the design of the structural part in this project, presenting the preliminary design of the structure.

Proposed Structure

The general view of the proposed steel structure, comprising three-storey, two bays by one bay, is shown in Figure 1 (a). The total height of the structure is 9 m; 3 m for each storey. The structure sits on a steel ringbeam (as shown in Figure 1 (a)), which is bolted to the shake tables, instead of to a concrete foundation. The elevation of X and Y directions is shown in Figures 1 (b) and (c).

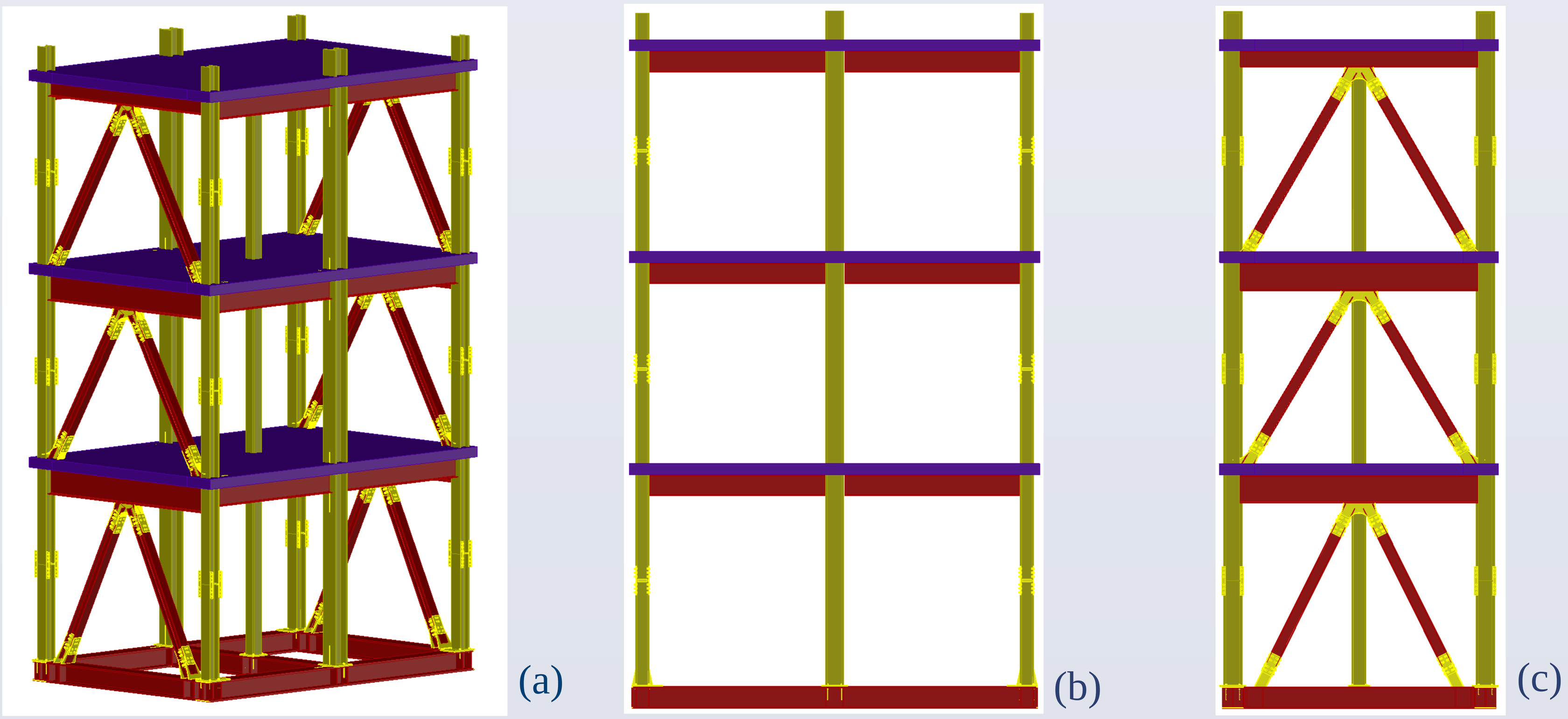

Figure 1: (a) 3 D View, (b) X Direction and (c) Y Direction of the Structure

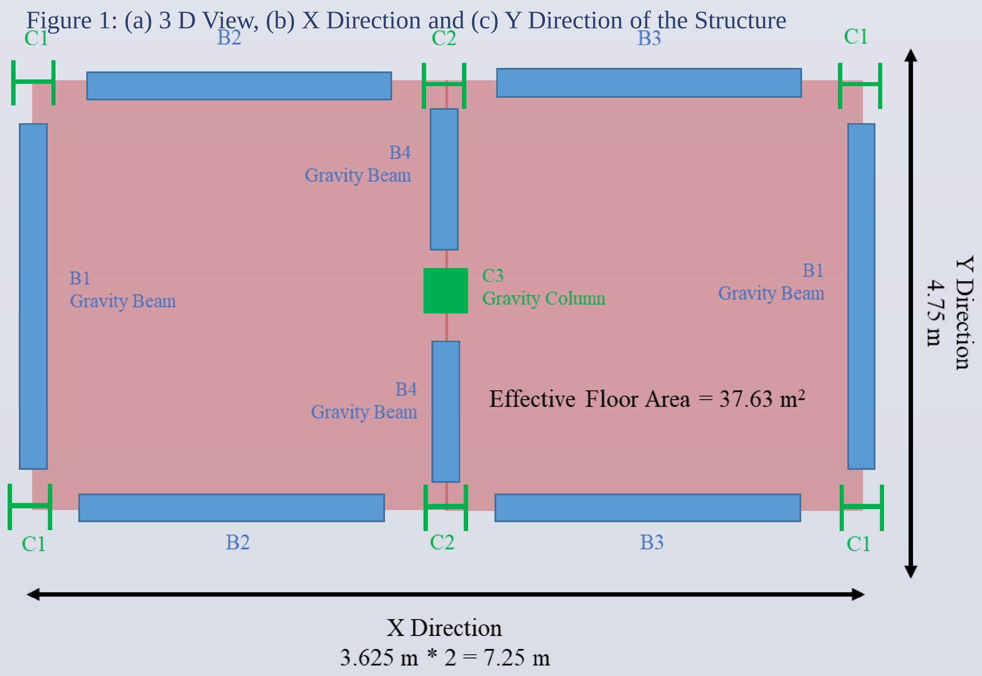

Figure 2: Plan View of the Structure

- Ductility Factor, μ = 3
- Importance Level, IL 2
- Return Period Factor, Ru = 1.0
- Structural Performance Factor, Sp=0.7
- Hazard Factor, Z = 0.4
- Near Fault Factor, N (T, D) = 1.0
- Wellington, Soil Class C, Shallow Soil
- Near Fault Distance, D = 0~8 km

Structural System Considered

The structural systems considered are shown below. There are mainly four types of structural systems, namely moment resisting frame (MRF), concentrically braced frame (CBF), dual system and rocking frame (RKF).

TYPE	SUBTYPE	LONGITUDINAL		LATERAL	NSE
		X		Y	
		Bay 1	Bay 2		
1	a	BRC CTB RSFJ	Pinned	CBF V-braced System with SFC Standard Weak	-
	b	BRC TOB RSFJ	Pinned	CBF V-braced System with SFC Standard Strong	-
	c	MRF RSFJ	Pinned	CBF V-braced System with SFC BSW	-
2	a	Pinned	SFC Brace (Diagonal), Pinned beam	CBF V-braced System with SFC BSW	-
	b	Pinned	Dual System	CBF V-braced System with SFC BSW	-
3	a	Pinned	MRF SHJAFC	RKF GnG	-
	b	MRF RSFJ	MRF SHJAFC	TJ Rocking Column	-
4	a	MRF RSFJ	MRF SHJAFC	CBF V-braced System with SFC	Full
	b	-	-	-	Full

BRC = Brace
BSW = With Belleville Washers
CBF= Concentrically Braced Frame
CTB = Compression/Tension Brace
Dual = SFC Braces + MRF-SHJAFC

GnG = Grip N Grab
Weak = Less Bolt Installed
Pinned = Pinned beam ends
RSFJ = Resilient Slip Friction Joint
RKF = Rocking Frame

SFC = Symmetric Friction Connection
STD = Standard with No Belleville Washers
Strong = More Bolts Installed
TOB = Tension Only Brace
TJ = Tongji

MRF Incorporating SHJAFC and SAFC Base

As shown in Figure 3 below, there are no bottom web bolts used in the design SHJAFC. The sliding will only take place at the bottom flange level where the AFCs are located. The reason is the joint would be too strong with the presence of bottom web bolts to be activated by a design level earthquake. Three rows of bolts at bottom flange level are used instead of two, in order to minimize the effect of prying on these bolts. The SAFC base (see Figure 4) is designed in a similar fashion as SHJAFC. It requires additional plates (cap plate) parallel to the column flange welded to the baseplate. The shear key is bolted to the ringbeam through the baseplate. Along the edge of the shear key, an angle is designed to allow the column sitting back to original position after uplifting occurs. Other type of shear keys can be easily installed when there is another purpose. The constructability of the SAFC base is better in this case. Any extreme rotation takes place in a sliding mode between two plates bolted together.

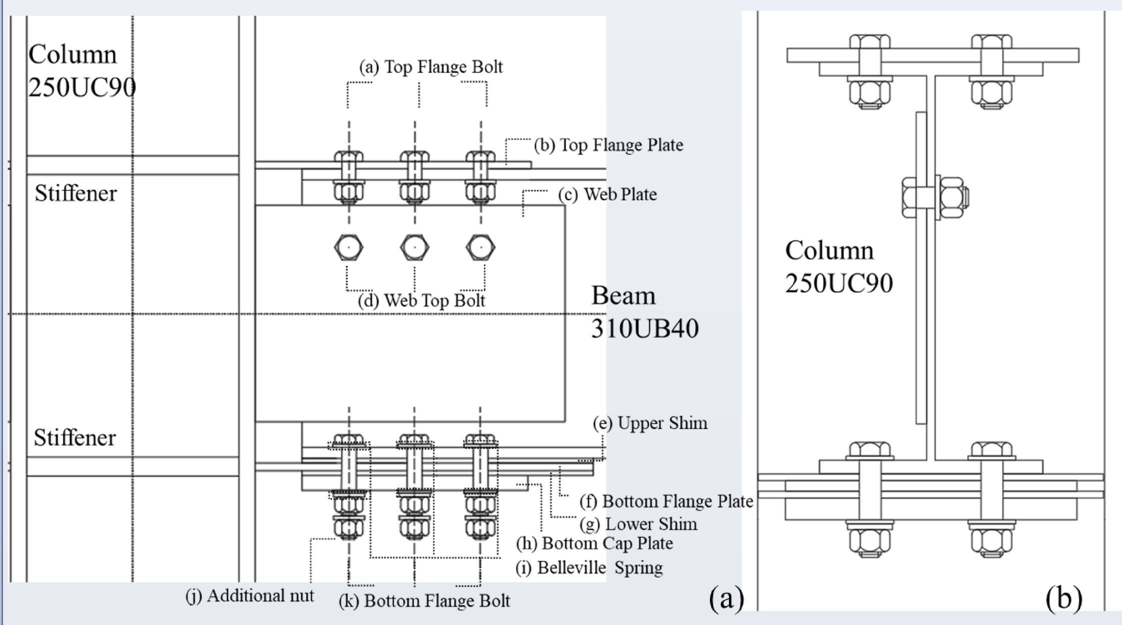

Figure 3: SHJAFC Layout (a) Lateral View and (b) Beam Cross Section View

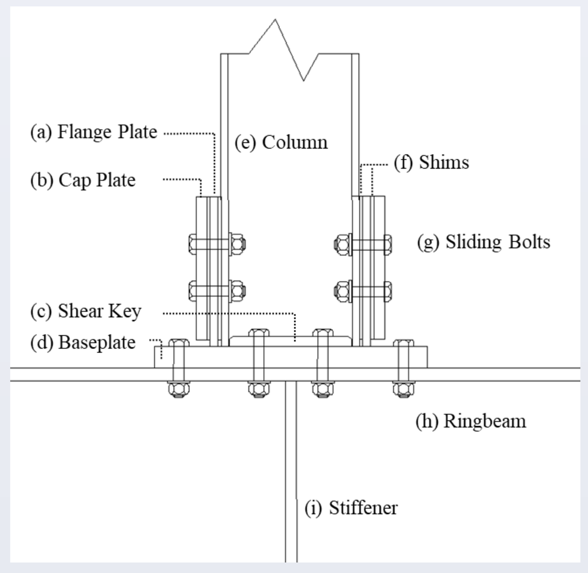

Figure 4: SAFC Base (a) Front View and (b) Plan View

Brace using SFC

The SFC is assembled by clamping the brace section, the slotted plate, and the shims by high strength bolts tensioned up to the proof load. RHS (back to back) is selected as brace section to provide stable out-of-plane behaviour.

The connection details at column base level of CBF X-braced system using SFC is shown in Figure 5. A slender vertical plate with oversized holes is welded to top of the shear key and bolted to the column web, limiting the possible uplift occurring at the column base. The slotted holes are designed in the gusset plate to provide a perfect SFC rather than in the brace section.

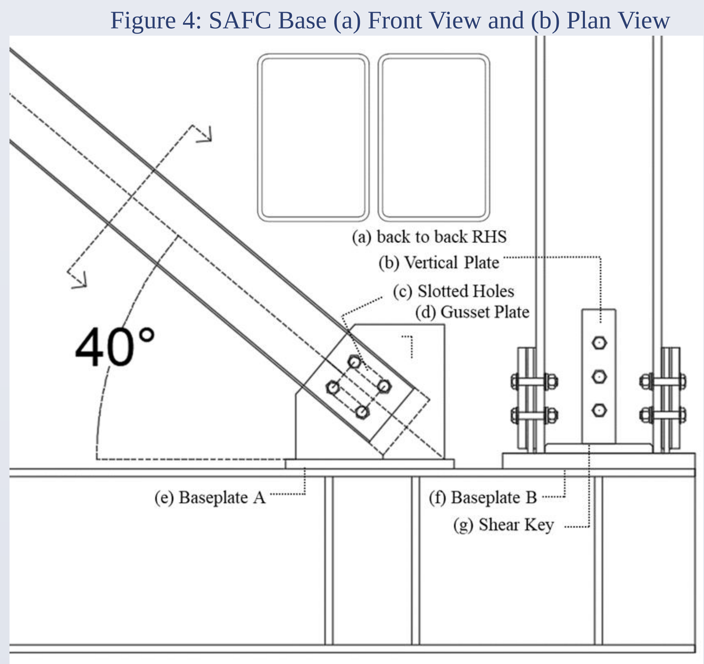

Figure 5: CBF Using SFC Brace

Rocking Frame incorporating GnG

The GnG (see Figure 6: (a)) is a tension-only dissipater device developed to offer resistance to loading in tension, while offering negligible resistance to compressive motion (Cook et al. 2016). The GnG device can be installed on the outside of the column flange or along the column web. A concrete filled steel tube hollow section is used as shear key (see Figure 6: (b)).

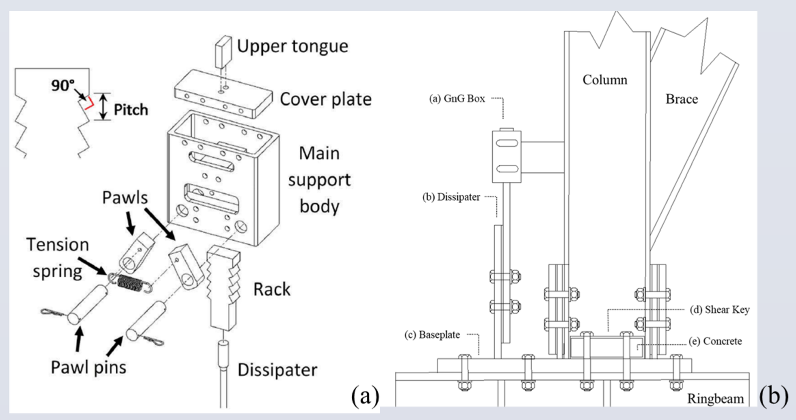

Figure 6: (a) GnG Device (Cook et al. 2018) and (b) Column Base Connection

Conclusions

This paper presents the preliminary plans and drawings of the proposed structure, reports on design progress that have taken place to date, and describes about the testing phase. The low damage structural systems being considered of the structure are discussed. Design example of SHJAFC with BeS is given. The use of SAFC base, low damage brace using SFC and rocking frame with GnG device are discussed, respectively. The testing will be conducted at ILEE facilities, Shanghai, China. This test is expected to provide an exemplar of how economic resilient technology can protect the whole building.

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